Applications of Industrial Wireless Sensor Networks

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CONTENTS

1.1 Introduction

Recent advances in wireless sensing technology encourages the further optimization and improvement of the product development and service provision processes. Industrial Wireless Sensor Networks (IWSN) are an emerging class of WSN that faces specific constraints linked to the particularities of the industrial production. In these terms, IWSNs faces several challenges such as the reliability and robustness in harsh environments, as well as the ability to properly execute and achieve the goal in parallel with all the other industrial processes. Furthermore, IWSN solutions should be versatile, simple to use and install, long lifetime and low-cost devices – indeed, the combination of requirements hard to meet.

In this chapter we discuss the applications of WSNs in industrial environments. Based on the specific requirements of the industrial production, the IWSN applications can be classified into three groups (Figure 1.1):

1. **Environmental sensing.** This group generally represents the widest field of WSN application nowadays. IWSN applications for environmental sensing cover the problems of air, water (together with waste water) *pollution*, but covers the production material pollution monitoring as well. Furthermore, in *hazardous* environments, there are numerous needs for fire, flood or landslide sensing. Finally, the *security* issues arise in markets with competing product and service providers, where IWSN are used for point of interest, area and barrier monitoring.
2. **Condition monitoring.** This group generally covers the problems of structural condition monitoring, providing both the structure health information (the condition of the buildings, constructions, bridges, supply routes, etc.) and machine condition monitoring including possible automatic maintenance. Therefore, this group of IWSN applications is vital for the production in all the branches of industry.
3. **Process automation.** The last group of applications provides the users with the information regarding the resources for the production and service provision (including the materials, current stock and supply chain status, as well as the manpower included in the industrial process). Finally, one of the most important issues from the user perspective is the production performance monitoring, evaluation and improvement, that are achieved through IWSNs.

Table 1.1 provides the list of major industry branches and sectors with the specific group of applications applicable to the particular branch. Here we consider 4 industry sectors: primary (the extraction of resources directly from Earth, includes farming, mining and logging with no product processing), secondary (primary sector product processing), tertiary (service provision) and quaternary (research of science and technology). Currently, the needs and possibilities of WSNs in all the industry sectors and branches are wide spread. The pace of industrial development pushes and encourages the development of IWSN even more. In this chapter, we analyze and evaluate current applications of IWSN and discuss possible future trends in this area.

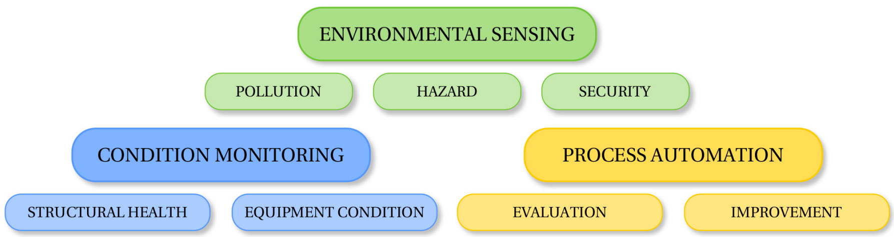

FIGURE 1.1
Taxonomy of industrial wireless sensor network applications.

TABLE 1.1
Main industry branches in 4 sectors.

Sector	Branch	Environmental			Condition		Process	
		Poll.	Haz.	Sec.	Struc.	Equip.	Eval.	Impr.
I	Mining, logging	•	•	•	•	•	•	•
I,II	Power/Energy		•	•	•	•	•	•
I,II	Agriculture	•	•				•	•
II	Chemical/Biotechnology		•	•			•	•
II	Civil engineering		•	•	•	•		
II	Electrical engineering			•	•	•	•	•
II	Mechanical engineering			•	•	•	•	•
II,III	Product processing		•	•		•	•	•
III	Transportation	•	•	•	•		•	
III	Military/Defense	•	•	•	•	•	•	•
III	Healthcare		•			•	•	
III	Communication			•		•	•	
III,IV	Security R&D			•		•		

In the following sections, we address some of the biggest challenges in IWSN in Section 1.2. Then, we provide the taxonomy of the IWSN applications for environmental sensing in Section 1.3, condition monitoring in Section 1.4 and process automation in Section 1.5. In Section 1.6 we present the extensive list of IWSN solutions and service providers. Finally, we discuss some possible future trends in Section 1.7.

1.2 Technological challenges

The deployment and the set up of Wireless Sensor Networks are extremely challenging tasks, which become even more challenging in industrial applications. The environment where IWSNs are deployed in order to monitor environmental or production processes is extremely dynamic, it can depend on the specific product, the phase of life of the product and the kind of service provision considered. In fact, each kind of product or phase of life has different requirements and imposes on the monitoring system different constraints. In this Section we will try to give a general description that can be useful for IWSNs' designers.

One of the challenges to face is the impact of the **propagation environment**. When the IWSN is deployed inside a factory to assess the production process quality, the designer has to deal with the interference and the radio environment produced by the production machines. In this case, the IWSN has to be deployed and calibrated not only to guarantee the correct assessment of the production process, but above all not to interfere with the production process. The same logic holds for IWSNs used to monitor electricity, water and gas consumption. Often nodes of the IWSN are immersed into the goods inside containers or any transportation means. For this kind of environments, the radio characteristics of the goods and the container have to be carefully investigated in order to determine the most efficient and effective way to make nodes communicate in spite of probable signal degradations.

In general, radio waves will not follow the same behavior according to the environments in which sensors are deployed. If the network is deployed outdoor, the radio propagation can be assimilated to a free-range perturbation, with an almost omni-directional propagation. However, it will be impacted by the weather, more or less depending of the frequency used. For instance, frequencies around $2.4GHz$ may be stopped by a thick fog. When wireless sensor networks are deployed indoor, the data propagation is far from being omnidirectional. In this environment it is even harder to make the classical assumptions on the shape and extension of the communication range for sensors. In fact, sensors that are placed within the communication range might be invisible, whereas sensors that should be considered out of range are actually in the neighbors' set. This can be explained by the fact that waves can bounce on walls, machinery, etc. This amplifies the signal in some locations and cancel it in other locations. Similarly, presence of metal and liquid greatly impacts the propagation. Indeed, metallic equipment may extend the propagation area for the radio signal or may prevent the signal to reach close areas beyond the equipment. These challenges, strictly dependent from physical factors, are not easy to handle. The environment in which sensors will be deployed needs to be studied in order to determine the optimal locations for sensors.

Operation lifetime, as a result of the power management policy, is one of the key issues in all the WSN applications, including the IWSN. Several IWSN applications, especially in the field of environmental monitoring, require the autonomous power supply from alternative power sources, such as wind or solar power. Although it is possible to obtain a constant power supply in some industrial environments, sensors tend to be battery powered in order to keep the monitoring non-intrusive. However, in most cases, batteries are not expected to be reloaded or changed. Thus, energy should be preserved. There exist many ways to do so, both in software and hardware. From the hardware point of view, it is important to carefully choose the components. These latter should be low energy consuming while providing the needed capacity. In some particular applications, energy harvesting modules can be envisioned, like solar cells or kinematic sensors, etc., but their usage is still marginal. From the software point of view, energy should be preserved by controlling the number of messages to be sent and the range.

Indeed, radio activities, such as sending and receving data are the activities that consume more energy in WSN compared with processing and sensing activities. Thus, it is important to monitor carefully the amount of data to send and the frequency at which it is sent, *i.e.* the number and size of messages, while preserving the quality of service expected by the application. Similarly, the further the messages are sent the more the energy needed and the more the interferences generated. Thus, it is important to monitor the transmission range based on the target to reach.

Another challenge in this field of application is the **heterogeneity** that the IWSN must deal with. In fact, heterogeneity is present in at least two different facets in industrial sensing applications: heterogeneity of *data collected* and heterogeneity of *objective network* to integrate with. The heterogeneity of data collected comes from the need of creating the dataset used to assess the quality of the production process/service provision by including a range spectrum of parameters. In turn, this requires to enable proper data fusion/data aggregation schemes for the acquisition/transmission of data, and powerful techniques of data analysis for the reception side. The heterogeneity of objective network is focused especially on logistics applications, where the IWSN used to monitor the transportation of some goods must be able to integrate with the IWSN deployed in both the production site and the delivery site, in order to acquire and exchange relevant information about the transported goods.

The third main technological challenge is that IWSNs for process and service monitoring have to **operate autonomously**. The operation of the IWSN should not represent an additional burden for the human involved in the sensor network operation, instead the IWSN should be able to autonomously configure and deploy when the deployment site is inaccessible for humans. In this context, **maintainability** is one of the important design challenges in the IWSN as well. The deployed IWSN and its components should be easily repairable or replaceable by maintenance personnel in the case of failures.

The requirements of the industrial process impose the need for reliable and secure IWSN. **Reliability** in this context refers to the monitoring system that has to provide accurate and real-time information regarding the monitored process even in harsh industrial environments under extreme vibration, noise, humidity or temperature conditions. The information gathered during the monitoring process is vital for proper system operations, given that even the smallest errors can produce fatal consequences for both the system and the product. Therefore, system **security** concludes our list of main challenges in the IWSN design.

1.3 Environmental sensing applications

1.3.1 Concept and objectives

Environmental sensing has been the basic WSN application, since WSN appeared in industrial processes. Nowaday, environmental sensing is widely spread in almost every field of industry. The common element that combines all the application scenarios together is the need for real-time information about the industrial environment, whether it is the production material, ambient or the process itself. Three different paradigms can be distinguished in this context: pollution, hazard and security monitoring, that will be discussed further in this section.

General objective in the environmental monitoring is an efficient information gathering, used both for prevention (real-time or postponed) and analysis. The migration from the wired sensor networks to their wireless counterpart brings numerous advantages by facilitating the deployment and information gathering process. However, the compromise is always present - WSNs still have to cope with the problems of erroneous communication, robustness, lifetime and cost constraints.

In this section we analyze some existing research works in the field of environmental sensing. Such environmental monitoring applications are the first ones that have been developed for wireless sensor networks. In fact, due to their small size, sensors can be easily and quickly deployed over large scales at low cost. Their wireless features that makes them independent from any costly and fixed infrastructures also contributed to their success. Environment sensing is a very broad area that comes from monitoring for disaster prevention, like volcano monitoring, to healing operations when sensors indicates a critic area.

1.3.2 Existing solutions

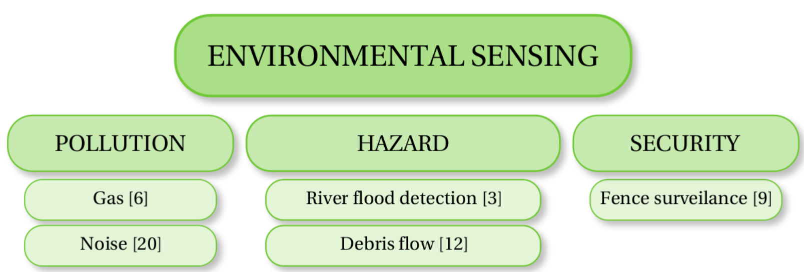

FIGURE 1.2
Environmental sensing applications.

FIGURE 1.3
Installation of water level sensor prototype for hazard prevention [3].

1.3.2.1 Pollution

The importance of the pollution detection both in materials for the production as well as in the production ambients makes the pollution monitoring one of the most widely spread field of application in environmental sensing. Constant advance in the sensing technology supports this statement as well. In [6], authors propose a low-cost, fully automated, end-to-end in-sewer gas monitoring system based on floating-drifting embedded sensor platform. This system provides the user with accurate information regarding the gas readings and its localization. Authors of [20] focus primarily on the noise pollution in urban areas. They present a prototype of a platform for collection and logging of the outdoor noise pollution measurements. These measurements can be used for the analysis of pollution effect on manpower productivity and social behavior. There also exist many other kinds of applications for detecting and/or preventing pollution like also air or water pollution continuously or after an event like for instance a volcano eruption which may spread in the atmosphere some toxic gas.

1.3.2.2 Hazard

Industrial facilities are often localized in environments that are riskier than residential areas, especially in the case of oil, gas and coal mining industries or agricultural companies. Therefore, proper early warnings or predictive disaster detection might be a valuable asset, resource and life saver. In [3], authors implement the river flood detection. A sensor network is used for flood prediction based on the previous measurements. By using a small number of sensor nodes with self-monitoring for failure capabilities, they cover and secure large geographical area under the threat of disaster (Figure 1.3). In [12], authors propose the debris flow monitoring system that allows in-situ real-time debris flow tracking. A number of robust sensors with self-localization capabilities are thrown into the flow, thus providing the real time flow direction and volume information used for early warning issuing.

1.3.2.3 Security

The concept of security in industrial environments is indeed widely spread over almost all the industry branches in all sectors. The security itself can refer to the security of the information and the security of the people, products and equipment. In this chapter, we focus on the latter. In this context, the applications for security monitoring usually focus on the area, barrier and point of interest monitoring. In [8], authors present a fence surveillance system that comprises the robot and camera sensor network and two types of nodes, ground and fence nodes. The network reports the acquired data to the base-station with issues commands to mobile robots that extend the communication distance of the system.

1.4 Condition monitoring applications

1.4.1 Concept and objectives

Why there is a need for WSN applications in condition monitoring? Every industrial system faces the problem of equipment amortization that introduces the maintenance cost into the equation. Moreover, there is a need for structural and equipment monitoring techniques that could provide global picture on subject condition and accurately predict equipment failures and therefore improve component and equipment reliability and performance. Furthermore, structural monitoring system detects system damages before possible failures and minimizes the time that production line spends out of service, and thus increases the profit. Without automated monitoring system, it is necessary to schedule regular system checks and preventively replace production equipment, which can also include the risk of sending maintenance workers into hazardous environments.

WSN intended for condition monitoring avoids all the aforementioned problems and suits the application requirements in comparison with wired sensing systems, since:

- it is easily deployable and reconfigurable even in an inaccessible areas such as moving (rotating) machine parts,
- it is easily reconfigurable,
- it reduces the system installation and condition monitoring cost in general.

In this context, we distinguish two classes of condition monitoring applications: **structural health** monitoring (public, private and transportation infrastructure) and **equipment condition** monitoring (mechanical and manufacturing equipment).

1.4.2 Existing solutions

1.4.2.1 Structural health monitoring

Wireless sensor networks are well suited for the structural health monitoring since they are easily deployable and configurable for this purpose. Here we cite some of the recent works that tackle the problem of structural monitoring (notably the vibration monitoring) on buildings [26], wind turbines [23], coal mines [13], tunnels [21] and bridges [7, 18].

In [26], authors deployed a wireless data acquisition system that is used for damage detection on the building. Their proposed system continuously collects structural response data from a multi-hop network of sensor nodes, displays and stores the data in the base station. They propose the system design and evaluate their approach by practical WSN implementation.

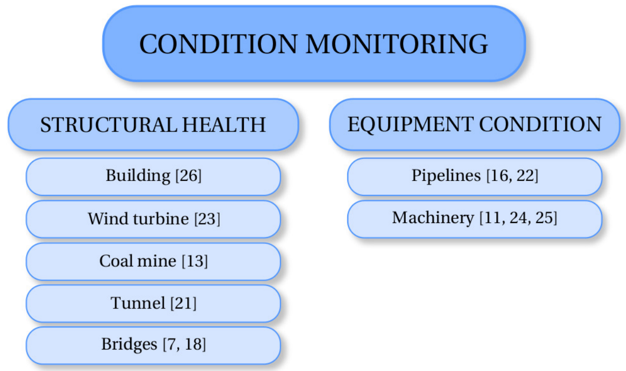

FIGURE 1.4
Condition monitoring applications.

Prior to the monitoring system implementation, it is necessary to characterize the structure under consideration. In [23], authors deploy wireless sensor network on two wind turbines in order to gather the vibrational output data and to provide better models of wind turbine dynamic behavior and response to loading (Figure 1.5). Authors made the acquired data available for future structure health monitoring designs.

Authors in [13] discuss the design of a structure-aware self-adaptive approach that rapidly detects structure variations in coal mines caused by underground collapses. The goal of their system design is to detect the collapsed area and report it to the sink node, to maintain the system integrity when the structure is altered and to provide a robust mechanism for query handling over the network under unstable circumstances. They conducted field experiments and deployed a prototype system that proves the approach feasibility.

One of the hot topics in structural monitoring research are bridges, as a part of the public infrastructure. Numerous research papers are written on this topic and there are numerous attempts to propose solutions and practical implementations for bridge health monitoring. We present only most recent works in this field. In [7], authors describe requirement, challenges, their design and implementation of WSN for health monitoring of Golden Gate Bridge in San Francisco Bay, USA. Authors identify requirements needed to obtain data of sufficient quality to have a real scientific value to civil engineering researchers for structural health monitoring. Furthermore, they propose the monitoring system that is scalable and applicable to different kinds of monitoring applications and address the typical problems encountered during the monitoring system practical implementations. In [18], authors present a low-cost wireless sensing unit designed to form dense wireless mesh networks. This device is developed for earthquake early warning projects, but it can be efficiently used as a tool for wireless structural monitoring as well. In order to determine the suitability of proposed system for structural monitoring appli-

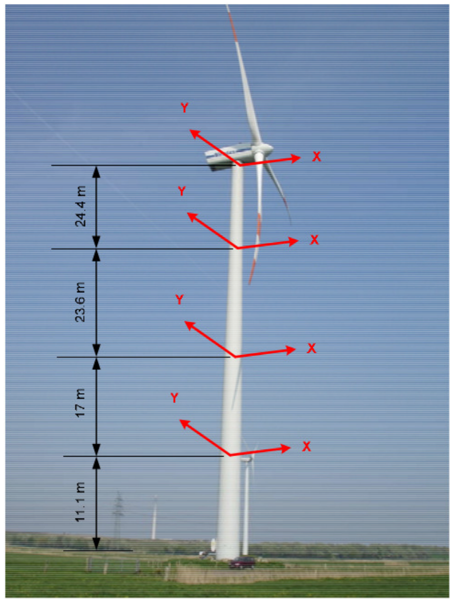

FIGURE 1.5
Locations of wireless sensors used for turbine health monitoring [23].

cations, they conduct experiments on Fatih Sultan Mehmet Bridge in Istanbul, Turkey. Finally, in [21], authors tackle some problems and solutions for structural health monitoring (especially for tunnels and bridges), but also discuss the current state and limitations of the sensing and wireless technology that is currently used. Their work presents advices for future experimental practice and lessons learned from three deployment sites in United Kingdom: Ferriby Road Bridge, Humber Bridge and London Underground tunnel.

1.4.2.2 Equipment condition monitoring

The production process speed and quality depends on the equipment condition and accuracy. In this section we present some of the recent works in the field of industrial equipment condition monitoring for pipelines [16, 22] and machinery [11, 24, 25].

In [16], authors develop the wireless network system for a team of underwater collaborative autonomous agents that are capable of locating and repairing scale formations in tanks and pipes within inaccessible environments. Authors describe in detail ad-hoc network hardware used in their deployments, that comprises the pH, proximity, pressure sensors and repair actuator. Furthermore, they describe the communication protocol and sensor/actuator feedback loop algorithms implemented on the nodes. Another work that focuses on WSN for pipeline monitoring is [22], where authors describe the WSN whose aim is to detect, localize and quantify bursts, leaks and other anomalies (blockages or malfunctioning control valves) in water transmission pipelines. Authors report the results and experiences from real deployment and provide algorithms for detecting and localizing the exact position of leaks that is tested in laboratory conditions. The system presented in this work is also used for monitoring water quality in transmission and distribution water systems and water level in sewer collectors. In this context, the work can be classified as the process evaluation group of works (Section 1.5.2.1) as well.

In [24], authors develop a WSN for machinery condition-based maintenance and they present design requirements, limitations and guidelines for this type of WSN applications. Furthermore, they implement their condition monitoring system in Heating & Air Conditioning Plant in Automation and Robotics Research Institute in University of Texas.

Authors of [25] propose the use of accelerometer based monitoring of machine vibrations and tackle the problem of predictive maintenance and condition-based monitoring of factory machinery in general. They demonstrate a linear relationship between surface finish, tool wear and machine vibrations thus proving the usability of proposed system in equipment monitoring.

In [11], authors focus on preventive equipment maintenance in which vibration signatures are gathered to predict equipment failure. They analyze the application of vibration analysis for equipment health monitoring in a central utility support building at a semiconductor fabrication plant that houses machinery to produce pure water, handle gases and process waste water for fabrication lines. Furthermore, authors deploy the same sensor network on an oil tanker in order to monitor the onboard machinery. In the end, they discuss design guidelines for an ideal platform and industrial applications, a study of the impact of the platform on the architecture, the comparison of two aforementioned deployments and a demonstration of application return on investment.

1.5 Process and service monitoring applications

1.5.1 Concept and objectives

The last group of applications that we have considered are those concerned with monitoring processes and services. In our acception, the former is industry-oriented and it consists of all the activities performed by human workers or machines to produce goods; whereas the latter is user-oriented and it consists of the operations needed to provide end-users with specific services, such as electricity or water provision.

Process monitoring involves many industrial fields, since it focuses on tracking the quality of the entire life of a product, step by step from the materials provision used for its production till its disposal. Therefore, all the IWSN applications dealing with manpower and production materials tracking as well as logistics and transportation systems fall in this category. The role of IWSNs in these applications is driven by the need for evaluating and improving each and every step of goods production-distribution-consumption process as well as the cycle as a whole.

Service monitoring is mainly related to evaluating the quality of the provision of a specific service to end-users. The quality assessment can be performed in terms either of the efficiency of the provision line or the effectiveness of the service provision at the end-user's location. In the first case, service monitoring overlaps with the public/private infrastructure monitoring already investigated in Section 1.4, whereas the second is object of study in what follows. In service monitoring applications the IWSNs have the important role of offering both the provider and the consumer valuable information about the provision. From providers' perspective, remote monitoring/metering of electricity power, heat, water or gas is a simple and effective solution, in fact it has gained a great momentum in the last years. From consumer's perspective, IWSNs' applications represent a remarkable step in the direction of the green building deployment because they allow end-users to constantly estimate their energy expenditure as well as the quality of the environment where they live.

The applications for both the fields studied in this section would highly benefit from the integration of the actuator system in order to automatically improve the process/service provision and achieve the desired results. For this reason, we split the existing solutions subsection in two parts: the first describes research works aimed at evaluating and monitoring processes and services provision, whereas the second includes also the actuation, which allow the designer to close the feedback control loop and move towards completely automated systems.

1.5.2 Existing solutions

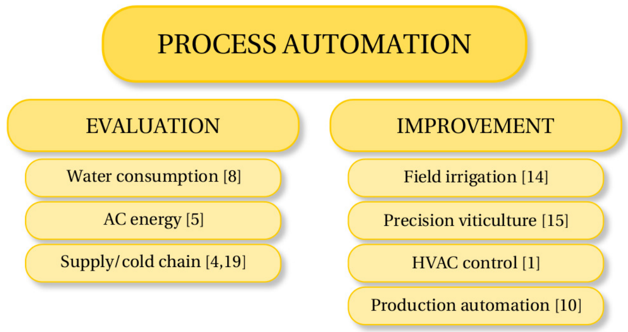

FIGURE 1.6
Process automation and service provision monitoring.

1.5.2.1 Process and service provision evaluation.

In this subsection we present some recent research works on developing IWSN applications aimed at gathering all the needed information from the product/service in order to asses the quality of the production/provision process. This kind of applications are very useful from both the private citizen's or company's perspective and the public system's perspective. For example, in the United States, the Environmental Protection Agency claims that more than $18 billion a year could be saved by reducing the water consumption by 30% and that the American public water supply and treatment facilities consume about 56 billion kWh per year, which is enough electricity to power over 5 million homes [2]. In [9], authors present an easy-to-install self-calibrating system that provides users with information on when, where, and how much water they are using. The approach is non-intrusive, cost-effective and easy to deploy. It is based on wireless vibration sensors attached to pipes, which are able to measure the water flow passing through the pipe and estimate consumption with a mean absolute error of 7%.

The United States Department of Energy in [17] estimated that 10% of the total energy used by commercial sector is wasted by parasitic energy use in commercial building HVAC systems. Green building deployment is the best response to this energy waste, but it will take some years before local and international communities and politics will accept and implement a different way to design and build public and private constructions. In the meantime, HVAC monitoring system are very useful to evaluate waste and consumption. For example, in [5], authors present a system for AC energy monitoring in large and diverse building environments. Their system provides real, reactive and apparent power measurements and comprises the metering control interface, IP compatible network structure and software that provides various power-centric applications.

As we said, the monitoring activities can involve also the life-cycle of a

FIGURE 1.7
Sensors deployed in a field for improved automated irrigation [14].

product, from its production to its disposal. Specifically, we have selected two research works that fall in the subcategory of resource tracking and logistics, in order to show how IWSNs, because of their intrinsic capability to deal with dynamic process, are well suited to be used in highly constrained and resource demanding processes. In [4], authors present a way to apply the dynamic WSN in temperature controlled supply chain (cold chain) for fruit and pharmaceutical product storage and transport to avoid degradation and spoilage. The approach supports real-time monitoring and remote maintenance via wired and mobile wireless network access. In [19], author presents the architecture and implementation of a self-configuring WSN used in a cold chain management tool that contributes to quality improvement and waste reduction.

1.5.2.2 Process and service provision improvement.

WSN dedicated for industrial process improvement represent maybe the most important part of all the industrially applicable WSNs since they usually comprise the actuator components as well. In this way, these IWSN could be observed as Automated Industrial Wireless Sensor and Actuator Systems, used for complete process automatization that are, therefore, wide spread and present in all the branches of industry. Backed up with the development of the sensing and communication component technology they represent the future of the Intelligent Process Automation Systems used in industry. A great number of works focuses on the agriculture production process amelioration. In [14], authors describe the design, development and deployment of a WSN that improves the water efficiency in the field irrigation located in dry regions. In this way, with the use of temperature and humidity information it is possible to implement the automated control system that consume irrigation water in efficient manner (Figure 1.7).

Authors of [15] present the architecture, hardware and the software of the platform used for precision viticulture. A major feature of this platform is its power-management subsystem, able to recharge batteries with energy harvested from the surrounding environment. It allows the system to sustain operation as a general-purpose wireless acquisition device for remote sensing in large coverage areas. The platform is currently being used as a simple and compact yet powerful building block for generic remote sensing applications, with characteristics that are well suited to precision viticulture.

In [1], authors tackle the problem of energy consumption control by presenting a novel control architecture that uses occupancy sensing to guide the operation of a building heating ventilation and air-conditioning systems. By interacting between sensing and actuating part of the HVAC control, they achieve significant results in energy saving.

In the context of highly dynamic processes in modern factory facilities, authors in [10] present a conceptual study of a wireless real-time system dedicated for remote sensor/actuator control in production automation. They discuss the emphasis on timing behavior and power consumptions and review the system design aspects such as network topology, multiple access schemes and radio technologies suitable for these constrained application environments.

1.6 Commercial solutions for IWSN

Commercial solutions for infrastructural and equipment monitoring include complete wireless system solution, comprising wireless data acquisition, vibration sensors, signal conditioning for vibration sensors, and signal processing software for equipment failure prediction and diagnostic. The sensors and network hardware used in these solutions is capable of coping with most of the aforementioned technological challenges. Table 1.2 provides a list of services and solution providers to which an interested reader should refer.

TABLE 1.2
Commercial solution and service providers for IWSN

No.	Name	Environmental sensing			Condition monitoring		Process automation		website
		Pollution	Hazard	Security	Structural	Equipment	Evaluation	Improvement	
1	ABB					•	•	•	abb.com
2	Accutech Instruments					•	•		accutechinstruments.com
3	AES	•	•		•	•	•	•	aesolutions.com.au
4	Aginova	•	•			•	•		aginova.com
5	Apprion				•	•	•		apprion.com
6	Augusta			•	•	•	•		augusta-ag.de
7	AVIDwireless	•	•			•	•	•	avidwireless.com
8	Azbil					•	•	•	azbil.com
9	Banner	•				•	•		bannerengineering.com
10	Bridge Diagnostics Inc.				•				bridgetest.com
11	Coalesenses	•	•						coalesenses.com
12	Dust					•	•		dustnetworks.com
13	Electrochem	•	•		•	•			electrochemsolutions.com
14	Elpro						•		elpro.com
15	Emerson					•	•	•	emerson.com
16	Endress+Hauser	•	•			•	•	•	endress.com
17	Ferguson Beauregard	•				•	•	•	fergusonbeauregard.com
18	FreeWave	•	•	•		•	•	•	freewave.com
19	GridSense					•			gridsense.com
20	GST				•	•			globalsensortech.com
21	Hitachi	•	•	•	•	•	•	•	hitachi.com
22	Invensys					•	•	•	invensys.com
23	Invisible Systems				•	•	•		invisible-systems.com
24	Meastim					•	•		meastim.com
25	Memsic	•	•			•	•	•	memsic.com
26	National Instruments					•	•	•	ni.com
27	Nivis	•	•			•	•		nivis.com
28	On-Ramp Wireless				•	•	•		onrampwireless.com
29	Panasonic	•		•		•	•	•	panasonic.com
30	Pepperl+Fuchs					•	•	•	pepperl-fuchs.co.uk
31	RF Code			•					rfcode.com
32	Rockwell	•	•	•		•	•	•	rockwellautomation.com
33	Scanimetrics				•	•			scanimetrics.com
34	Sensormetrix	•	•	•			•		sensormetrix.co.uk
35	Siemens	•	•	•	•	•	•	•	automation.siemens.com
36	SKF				•	•			skf.com
37	Synapsense	•	•						synapsense.com
38	Timken					•	•	•	timken.com
39	Wessex Power	•	•				•		wessexpower.co.uk

1.7 Discussion and trends

Following the above description of the available wireless sensor network solutions for industrial applications, in this section we propose a discussion about open issues and future trends for different type of industrial applications in environmental sensing, condition monitoring and process automation.

Environmental sensing. Depending on the environment in which sensors will be deployed, the *hardware* should be carefully studied. Indeed, environment monitoring refers to outdoor applications. Thus, sensors should be water-proof, prone to shocks, etc. This has a cost which represents a real challenge since such applications require the deployment of a great number of sensors, which can not be done if each single sensor is expensive. An important feature of wireless sensor networks deployed for environment monitoring is that the *environment is not controlled*, not controllable and possibly not easily accessible, *i.e.* if a sensor is moved (by animals or wind for instance), the network must continue to work properly. Network basic mechanisms such as neighbor discovery or routing must adapt this mobility. This remains a great challenge.

Condition monitoring. Recent technological advances will permit the development of intelligent sensors and therefore the development of low-cost *intelligent monitoring systems* capable of reliable equipment failure prediction. Furthermore, technological advances allow the development of structures, production lines and individual equipment components with built-in sensors, emergence of *self-monitoring equipment* that would behave as an ad-hoc network and that would easily communicate with other parts of condition monitoring system. In the context of automation and maintainability, the integration of complex software solutions onto sensing network and sensor firmware that would introduce the concept of *failure prediction* and real-time problem *diagnostics*. In the end, all the acquired condition monitoring information provide important guidelines and could serve the purpose of "to do" list for future civil infrastructure and production equipment design and construction.

Process automation. Designers and developers of Wireless Sensor Networks have lost their initial view of WSN as a single system composed of simple and homogeneous devices. From the referenced works, we have seen that, especially in industrial applications of WSNs for process and service monitoring, the trend is to deploy pervasive systems of *heterogeneous capabilities*. These systems look at the nodes capabilities as the constituent blocks for designing new applications and, in turn, this calls for a standard communication paradigm. The process monitoring also offers the possibility to pave the way for the concept of *"plug-in network"*, which is a network of heterogeneous device able to become part of a larger network, when some spatial proximity condition is satisfied. Therefore, we can imagine networks of devices deployed in a container to monitor the transportation conditions of some goods, which are able not only to communicate immediately with the "driver" if a problem occurs, but also participate in successive phases of the consumption phase once they arrive on the delivery site. Specifically for service provision monitoring, as we have already said the IWSN deployed to measure consumption and quality of the service provided represent an important step towards the *design of green building* where the consumption of energy is limited by new construction techniques, but IWSN can ensure a continuous and constant monitoring and fixing of consumptions, failures, wastage, etc. IWSN applications for process and service provision have gained a lot of market in the last years, because of the *complete control* they offer in the whole life-cycle of a product, it is very likely that the growth of this technology in the years to come will be even stronger, if designers and developers are able to create high-specialized products for specific needs as well as cheap and customizable platforms for householders and small companies.

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